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(54) **POWDER FEED ASSEMBLY FOR AN ENRICHED AIR FLAME SPRAY APPARATUS AND ASSOCIATED METHOD**

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B05B 15/00 (2006.01)

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CPC ***B05B 7/144*** (2013.01); ***B05B 15/003*** (2013.01)

(58) **Field of Classification Search**
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USPC 222/410, 414, 342, 326, 1, 367, 333, 222/195, 334; 417/414; 406/146, 137, 52; 266/182; 164/200; 137/615, 14
See application file for complete search history.

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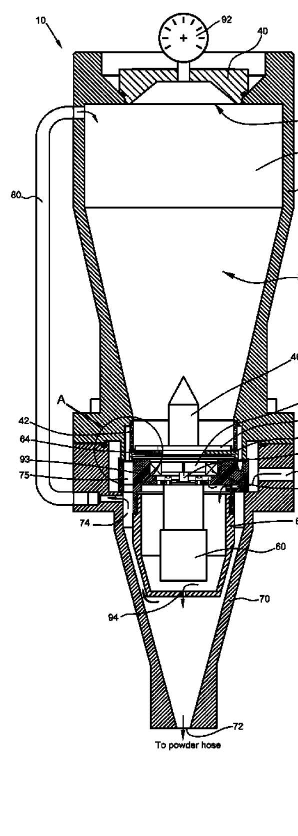
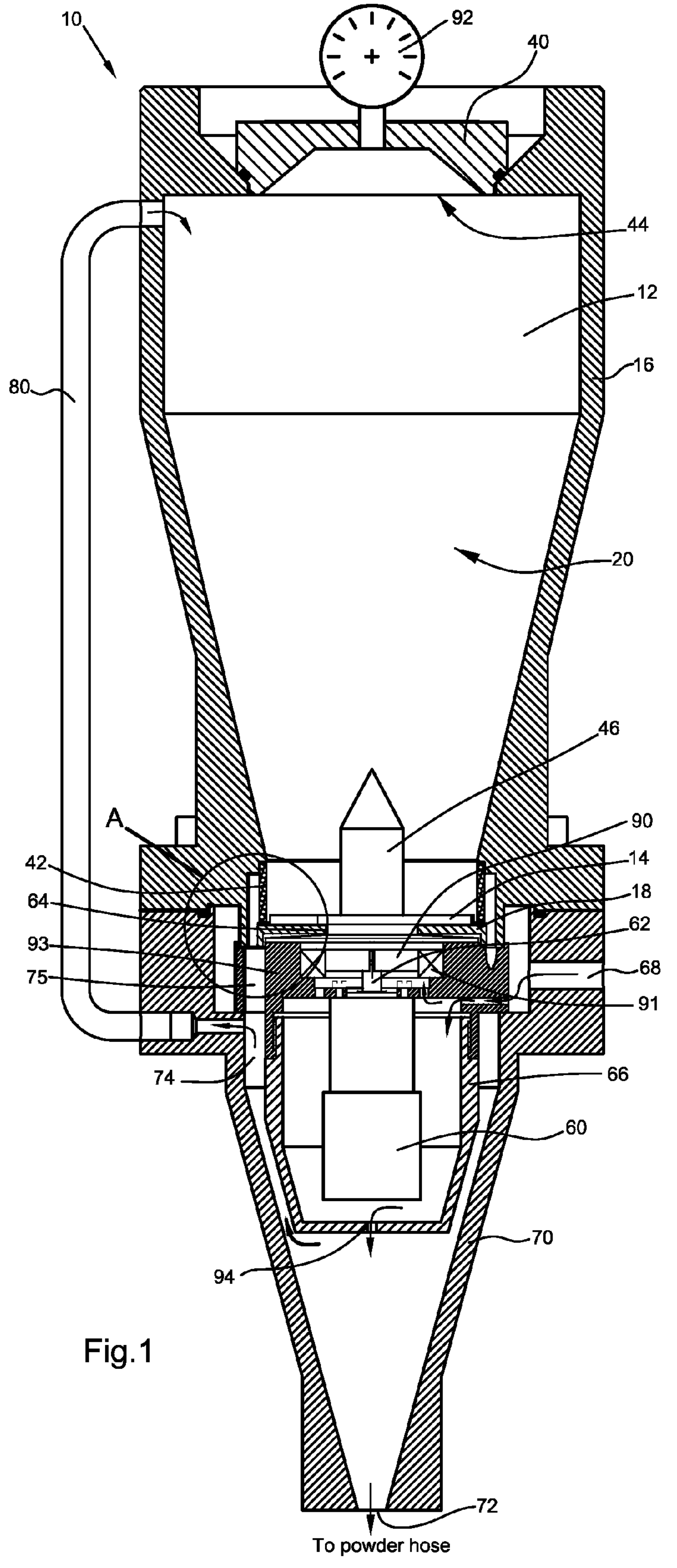
(57) **ABSTRACT**

A powder feed assembly comprises a powder hopper and a selectively rotating blade. The powder hopper has a wall and a floor together forming a chamber. A circumferential horizontal gap is defined between the wall and the floor to enable powder to exit the chamber. The selectively rotating blade has a body portion positioned within the chamber and one or more blade portions at least partially extending into the gap.

15 Claims, 8 Drawing Sheets

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To powder hose

Fig.1

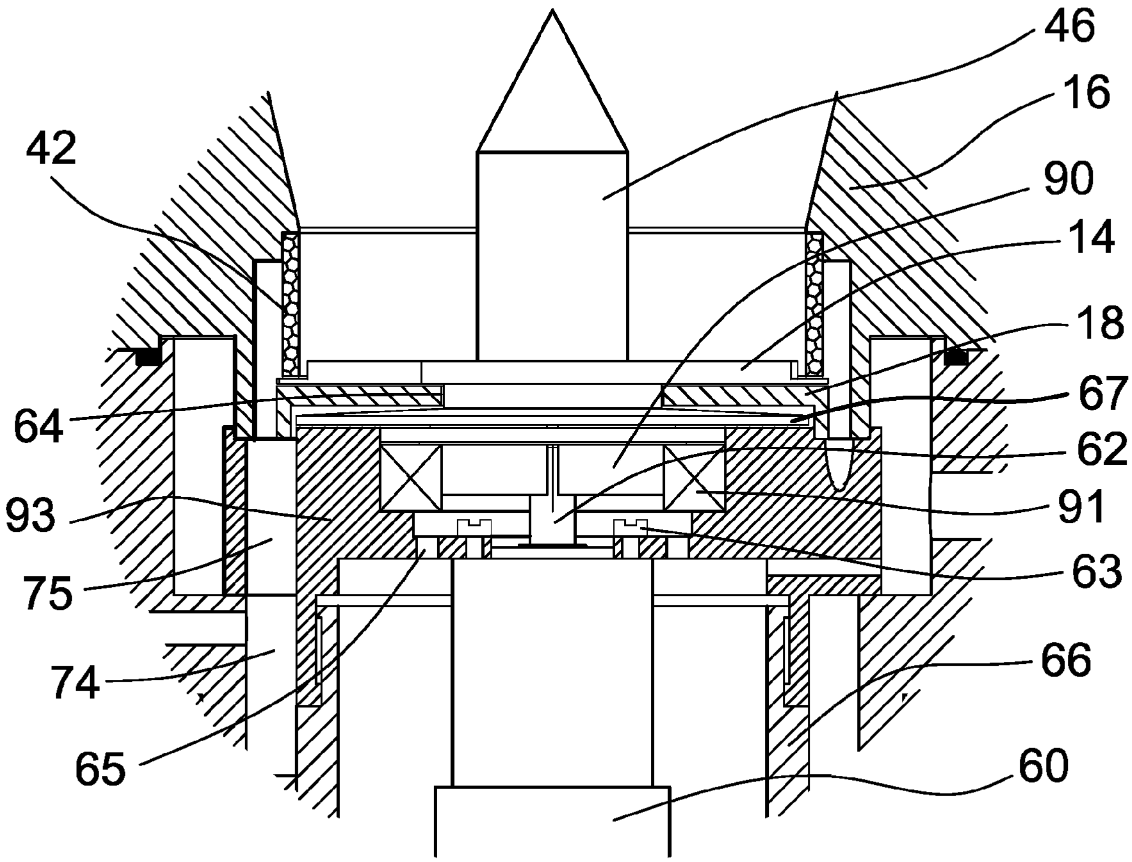

Fig.1a

A (4:1)

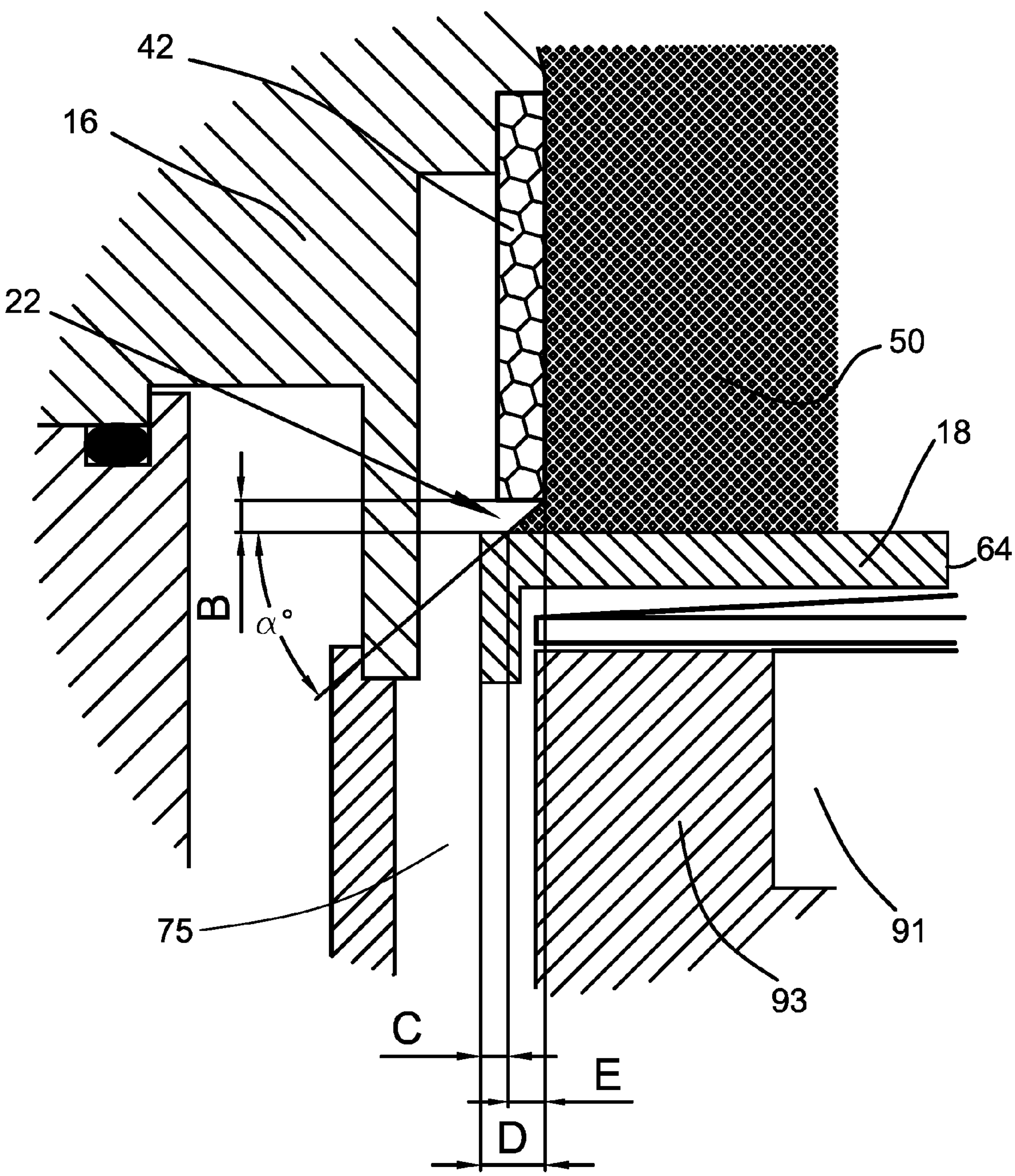

Fig.2

A (4:1)

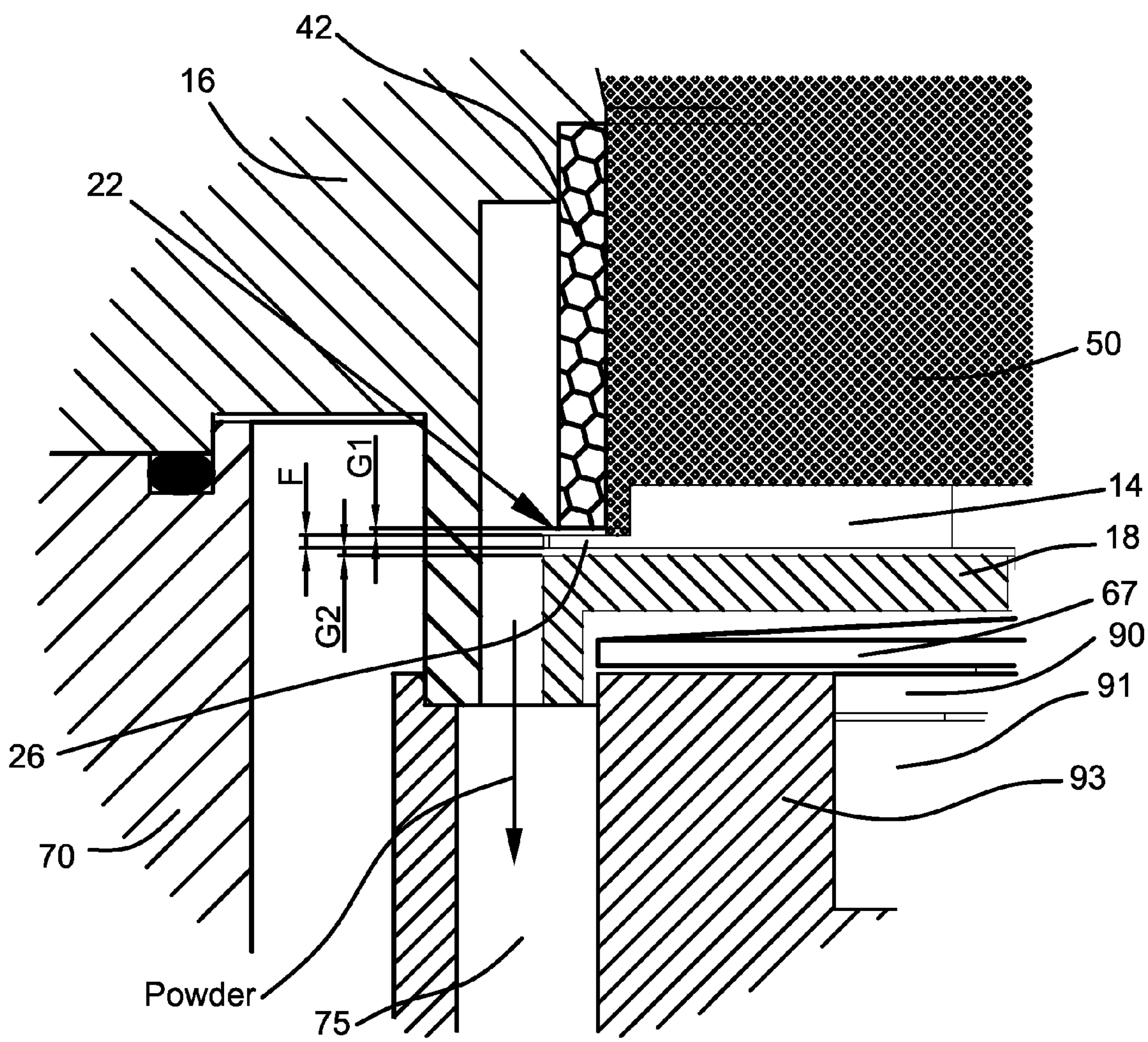

Fig.3

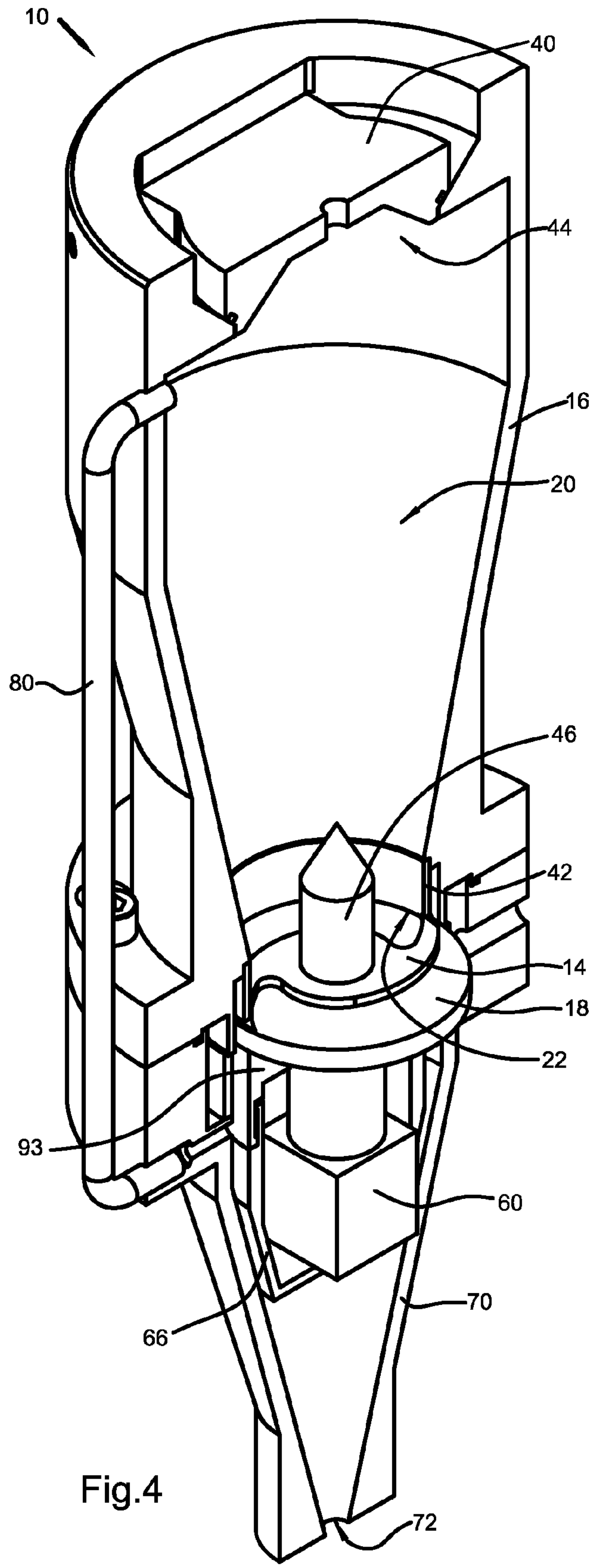

Fig.4

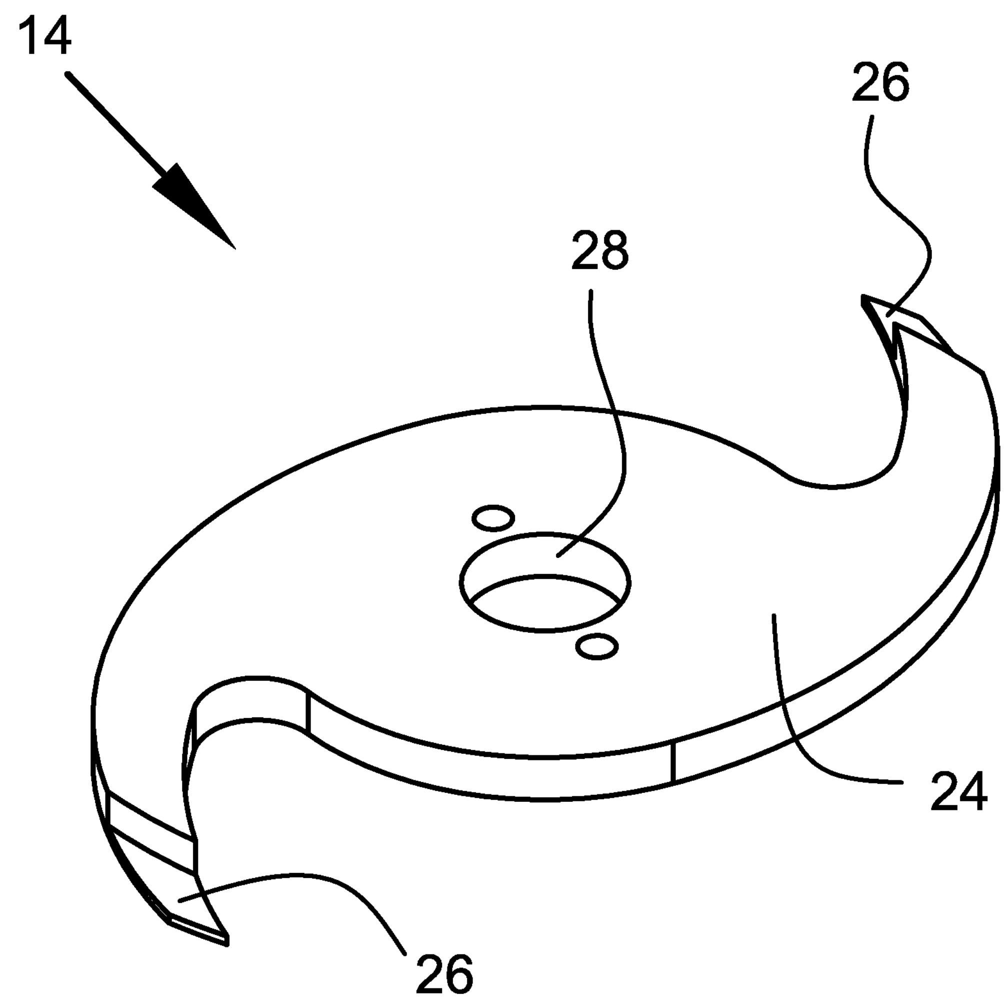

Fig.5

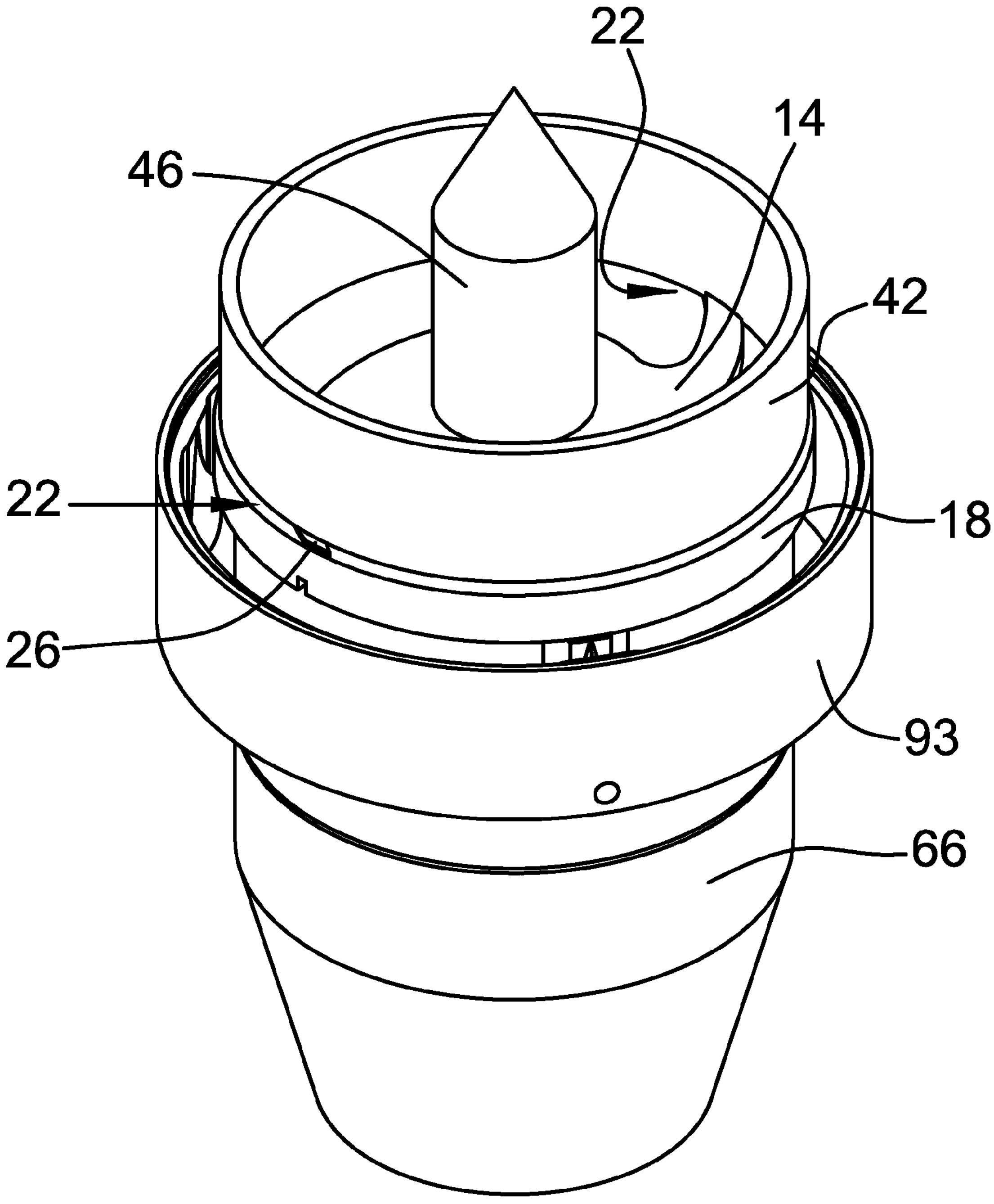

Fig.6

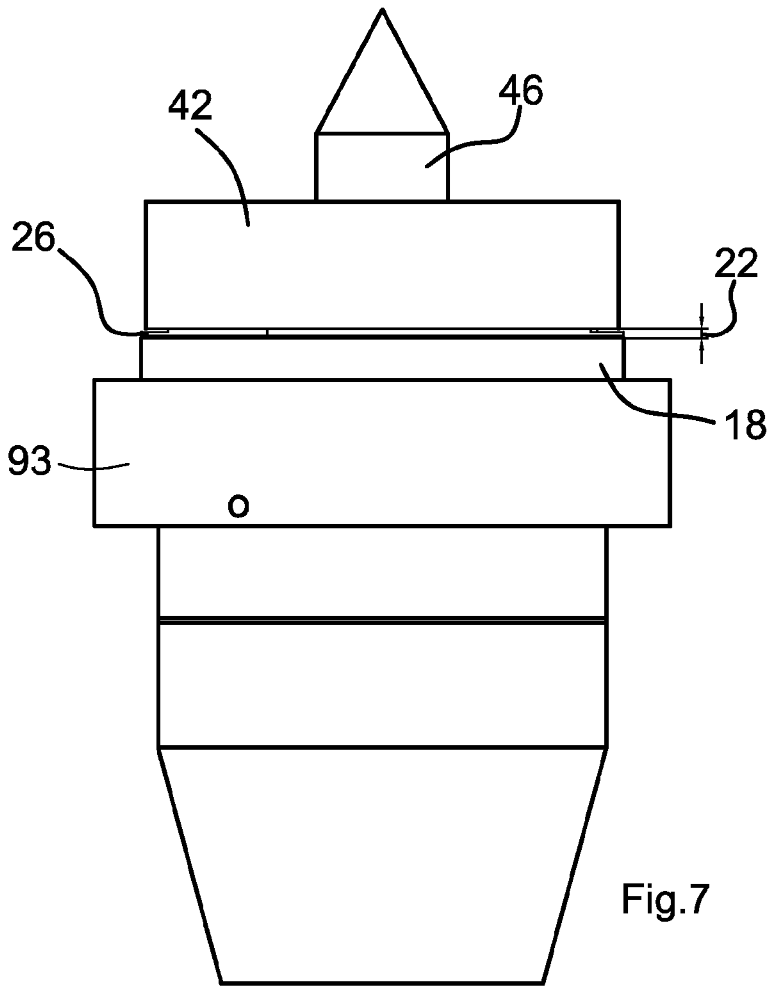

Fig.7

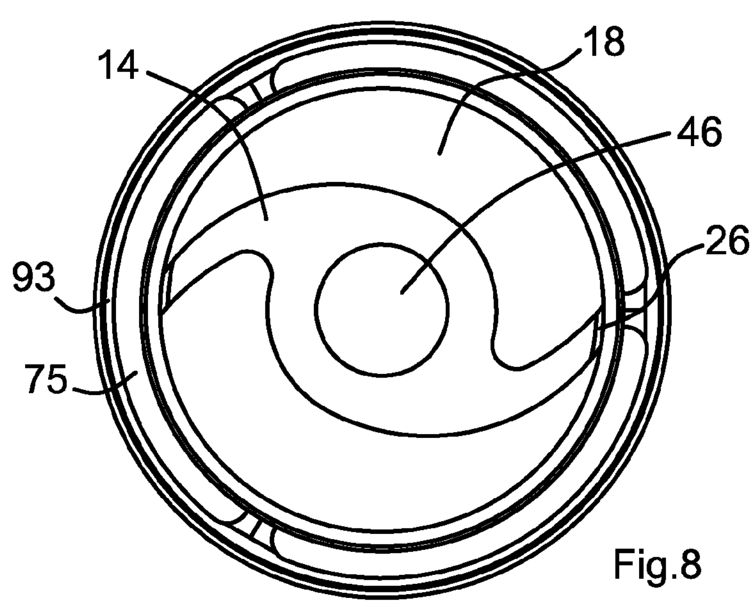

Fig.8

POWDER FEED ASSEMBLY FOR AN ENRICHED AIR FLAME SPRAY APPARATUS AND ASSOCIATED METHOD

FIELD OF THE INVENTION

The present invention relates generally to powder feeding, and more particularly to an apparatus and method for feeding powder to an enriched air flame spray apparatus.

BACKGROUND

Thermal spraying is widely used to apply metals and ceramics in a form of coating or bulk materials on different types of substrates. A majority of thermal spray methods utilize energy of hot gaseous jets to heat and accelerate particles of spraying material. When impinging the substrate, the particles form a coating.

The particles of material to be sprayed, such a metal or ceramic, are provided to the thermal spray apparatus as a powder. A powder feeding apparatus is used to provide a controlled amount of powder to the thermal spray apparatus. Conventional powder feeding apparatuses have several shortcomings, such as wearing seals and non-uniform powder metering. Wearing seals are a common feature of conventional powder feeding apparatus design, and necessitate frequent replacement of seals to prevent formation of gaps and maintain proper operation. When used with abrasive powders, some powder feeders require seal replacement as often as every few hours. This not only adds to operating costs, but also has a disadvantage of necessitating the removal of the powder feeder from service in order to perform the required maintenance, effectively shutting down the entire thermal spray coating application process until the powder feeder maintenance is performed. Another shortcoming of conventional powder feeding apparatus design is the pulsation of the powder stream, which results from discrete metering of the powder material. Conventional metering mechanisms generally utilize slots or holes of fixed volume, into which the powder material is packed, and from which the powder material is dispensed into the powder stream in batches, resulting in a non-uniform powder stream.

BRIEF SUMMARY

In one embodiment of the invention, a powder feed assembly for an enriched air flame spray apparatus comprises a powder feed assembly comprises a powder hopper and selectively rotating blade. The powder hopper has a wall and a floor together forming a chamber. A circumferential horizontal gap is defined between the wall and the floor to enable powder to exit the chamber. The selectively rotating blade has a body portion positioned within the chamber and one or more blade portions at least partially extending into the gap.

A height of the gap and/or a width of a portion of the floor which extends circumferentially beyond an interior surface of the wall adjacent the gap may be selected based on an angle of repose of the powder.

A height of the gap and/or a width of a portion of the floor which extends circumferentially beyond an interior surface of the wall adjacent the gap may be selected such that the powder does not exit the chamber through the gap when the blade is not spinning.

A height of the gap and/or a width of a portion of the floor which extends circumferentially beyond an interior surface of the wall adjacent the gap may be selected such that the width of the portion of the floor which extends circumferentially beyond the interior surface of the wall adjacent the gap may be greater than a distance that the powder extends into the gap beyond the interior surface of the wall adjacent the gap when the blade is not spinning. The distance that the powder extends into the gap beyond the interior surface of the wall adjacent the gap may correspond to an angle of repose of the powder.

The assembly may further comprise a motor and a motor housing. The motor may be positioned beneath the floor and has a selectively rotating shaft to which the blade is directly or indirectly affixed. The shaft may extend at least partially through a shaft hole defined in the floor. The motor housing may at least partially surround the motor and may have a carrier gas inlet to enable a carrier gas to be introduced into the motor housing to pressurize the housing.

The assembly may further comprise a receiving funnel positioned to receive powder exiting the chamber through the gap and to supply the received powder to a hose.

The assembly may further comprise a pressure-equalizing pipe fluidly connecting the chamber and the receiving funnel to enable pressure equalization therebetween.

At least a portion of the hopper wall may be porous. The porous portion may have a plurality of holes defined therein, a size of the holes selected to permit a carrier gas to exit the chamber through the porous portion but to not permit the powder to exit the chamber through the porous portion. The porous portion may be positioned between the chamber and an inner volume of the receiving funnel.

The assembly may further comprise a porous bushing having a plurality of holes defined therein, a size of the holes selected to permit a carrier gas to exit the chamber through the porous bushing but to not permit the powder to exit the chamber through the porous bushing. The porous bushing may be positioned between the chamber and an inner volume of the receiving funnel.

In addition to powder feed assembly for an enriched air flame spray apparatus, as described above, other aspects of the present invention are directed to corresponding methods for feeding powder.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING(S)

Reference is made herein to the accompanying drawings, which are not necessarily drawn to scale, and wherein:

FIG. **1** is a cross-sectional side view of a powder feeding apparatus, in accordance with embodiments of the invention.

FIG. **1***a* is an enlarged view of a central portion of the powder feeding apparatus of FIG. **1**.

FIG. **2** is a first enlarged view of a first section (marked "A" in FIG. **1**) of the powder feeding apparatus of FIG. **1**, with the blade omitted for simplicity.

FIG. **3** is a second enlarged view of the first section (marked "A" in FIG. **1**) of the powder feeding apparatus of FIG. **1**.

FIG. **4** is a cross-sectional perspective view of the powder feeding apparatus of FIG. **1**.

FIG. **5** is a perspective view of the blade of the powder feeding apparatus of FIG. **1**.

FIG. **6** is a perspective view of the feeding mechanism of the powder feeding apparatus of FIG. **1**.

FIG. **7** is a side view of the feeding mechanism of the powder feeding apparatus of FIG. **1**.

FIG. **8** is a top view of the feeding mechanism of the powder feeding apparatus of FIG. **1**.

DETAILED DESCRIPTION

Embodiments of the invention comprise a powder feeding apparatus. A powder feeding apparatus of embodiments of the invention may be used to supply powder to a thermal spray apparatus, although embodiments of the invention are not limited to use with thermal spray apparatuses.

Referring now to FIGS. **1-8**, a powder feed assembly **10** comprises a powder hopper **12** and a selectively rotating blade **14**. The hopper **12** has a wall **16** and a floor **18** together forming a chamber **20** for holding a powder to be fed to, for example, a thermal spray apparatus (the powder is omitted from FIGS. **1**, **1***a*, and **4-8** for clarity). As seen in FIG. **1**, the wall **16** has a generally vertical upper portion, a generally conical middle portion, and a generally vertical lower portion, although other suitable shape profiles may be used. A circumferential horizontal gap **22** (seen in FIGS. **2** and **3**) is defined between the wall **16** and the floor **18** to enable powder to exit the chamber. An opening **44** is defined in the top of the hopper **12** for adding powder into the hopper. The opening **44** is selectively closed off via selectively removable cap **40**. A pressure gauge **92** may be attached to a port defined in the cap **40**, for measuring the pressure within the chamber **20**.

The selectively rotating blade **14** has a body portion positioned wholly within the chamber and one or more blade portions at least partially extending into the gap **22** (and potentially extending all the way through the gap). Having one or more blade portions at least partially extending into the gap enables the blade to push powder that is within the chamber **20** out through the gap **22** in a consistent and controlled manner. The rotational speed of the blade can be varied as needed to increase or decrease the amount of powder that is pushed out through the gap **22**. The selectively rotating blade may be constructed out of any suitable material, such as any suitable metal or metal alloy. It may be desirable for at least the blade portions to be constructed out of a softer, more flexible material (including but not limited to rubber) which may help prevent powder particles from becoming wedged between the blade portions and the surface(s) of the gap **22**.

FIG. **5** illustrates one embodiment of the blade that may be used with a powder feed assembly of embodiments of the invention. Blade **14** of FIG. **5** has a body portion **24** and two opposing blade portions **26** (the blade portions **26** may also be termed "arms"). It is desirable to have the body portion **24** to be thicker than blade portions **26** for better agitation of powder and preventing the powder from bridging in the chamber **20** when the blade is spinning. Blade **14** also has a center hole **28** defined therein for attaching the blade **14** to a motor shaft (described below). While FIG. **5** illustrates a blade having two blade portions or arms, blades of alternative embodiments of the invention may alternatively have one blade portion or may have more than two blade portions. The blade portion(s) extending into the gap **22** is seen at least in FIGS. **3**, **6**, **7** and **8**.

A nut **46** is affixed to the motor shaft to secure the blade in place. The nut **46** has an elongated vertical shape with a conical top. The shape of the nut **46** helps direct powder within the chamber **20** toward the wall **16** of the chamber, to better facilitate the blade pushing the powder through the gap **22**.

The hopper **12** may include a porous bushing **42** having a plurality of holes defined therein. The size of the holes is selected such that a carrier gas (discussed further below) is able to exit the chamber **20** through the porous bushing but such that the powder is not able to exit the chamber **20** through the porous bushing. In other words, the holes in the porous bushing are larger than the molecules of the carrier gas but smaller than the particles of the powder. The number of holes (which may be controlled by the size of the porous bushing) may be selected to enable the amount of carrier gas exiting in that manner to be controlled. When the hopper is under pressure, the carrier gas is within the powder mass in addition to being above or below powder. When the spray gun is stopped, this gas within the powder starts releasing pressure by flowing out through all possible holes (which, in the absence of the porous bushing would be just the gap **22**) and then out through the powder hose. Obviously, this flow of carrier gas drags powder through the gap **22**, which creates undesirable powder after-flow through the spray gun, resulting in wasted powder. The porous bushing minimizes or prevents this by providing multiple passages for gas to escape to release pressure but not allowing powder to flow through holes. Some carrier gas will still flow through the gap **22**, but the gas flow through the gap **22** becomes small enough that it does not entrain the powder through the gap).

The height of the gap **22** (dimension "B" in FIG. **2**) and/or the width of the portion of the floor **18** which extends circumferentially beyond the interior surface of the hopper (formed by the porous bushing **42**) adjacent the gap (dimension "D" in FIG. **2**) may vary depending on the angle of repose of the powder to be fed. Dimension "B" and/or dimension "D" is/are selected such that the powder does not exit the chamber through the gap **22** when the blade is not spinning. One way to accomplish this is to ensure that dimension "B" and/or dimension "D" is/are selected such that dimension "D" is greater than a distance that the powder extends into the gap **22** beyond the interior surface of the wall adjacent the gap (dimension "E" in FIG. **2**) when the blade is not spinning. The difference between dimension "E" and dimension "D" is labeled as dimension "C" in FIG. **2**.

The distance that the powder extends into the gap beyond the interior surface of the hopper (which is formed by the porous bushing **42** in the illustrated embodiment, or by the wall **16** if no porous bushing is used) adjacent the gap when the blade is not spinning (dimension "E" in FIG. **2**) corresponds to an angle of repose of the powder. Angle of repose is the steepest angle of descent relative to the horizontal plane in which a material can be piled without slumping. The angle of repose of powder **50** in FIG. **2** is labeled "$\alpha°$". The angle of repose of the powder **50** determines how far past the interior surface of the hopper (which in the illustrated embodiment is actually the interior surface of the porous bushing **42**) the powder **50** will naturally fall (dimension "E" in FIG. **2**). The taller the gap **22** is (dimension "B" in FIG. **2**), the farther past the interior surface of the hopper the powder **50** will naturally fall (dimension "E" in FIG. **2**) and therefore the wider the portion of the floor **18** which extends circumferentially beyond the interior surface of the hopper adjacent the gap (dimension "D" in FIG. **2**) should be. Conversely, the shorter the gap **22** is (dimension "B"), the less far past the interior surface of the hopper the powder **50** will naturally fall (dimension "E") and therefore the less wide the portion of the floor **18** which extends circumferentially beyond the interior surface of the hopper adjacent the gap (dimension "D" in FIG. **2**) should be. The height of the gap **22** (dimension "B" in FIG. **2**) is typically selected (along with the thickness of the blade portion and relative position of the blade portion within the gap—discussed further below) to ensure that the desired amount of powder is fed from the chamber **20** during operation of the powder feed assembly **10**. It is typically known which powder(s) will be used in the powder feed assembly **10**, and therefore the angle(s) of repose is/are typically known. As such, the width of the portion of the floor **18** which extends circumferentially beyond the interior surface of the hopper adjacent the gap (dimension "D" in FIG. **2**) would typically be determined based on the gap height and the shallowest angle of repose for whichever powder(s) will be used in the powder feed assembly **10**.

The thickness of the blade portion **26** (dimension "F" in FIG. **3**), the height of the gap **22** (dimension "B" in FIG. **2**), and the position of the blade portion **26** within the gap **22** are all selected such that gap above the blade portion (dimension "G**1**" in FIG. **3**) and the gap below the blade portion (dimension "G**2**" in FIG. **3**) are both larger than the largest particle of powder expected to be fed using the powder feed assembly of embodiments of the invention.

The powder feed assembly of embodiments of the invention further comprises a motor **60** positioned beneath the floor **18** and attached to motor housing base **93** with screws **63**. The electrical and control connections to the motor **60** are omitted from the figures for simplicity. The motor **60** has a selectively rotating shaft **62** to which the blade **14** is affixed (directly or indirectly). The shaft **62** extends at least partially through a shaft opening defined in the floor **18**. In the illustrated embodiment, as seen in FIG. **1***a*, the motor shaft **62** actually is attached to a blade holder **90** that is sitting on a bearing **91**. The blade is affixed to the blade holder **90**. Such an indirect connection between the blade and the motor shaft is desirable to minimize/eliminate the axial run out of the blade and secure its position in the gap. The blade holder **90** may have a deflector portion **67** that helps prevent powder (that may fall from the chamber **20** through the opening **64**) from getting into the bearing **91** and motor **60**.

The motor **60** is at least partially surrounded by a motor housing **66**. The motor housing **66** is affixed to the motor housing base **93** below the floor **18**. In conventional powder feed devices, the carrier gas is introduced into a powder hopper to propel the powder within the hopper through a screened floor. The carrier gas carries the powder particles from the hopper all the way to the thermal spray apparatus. It is necessary in conventional powder feed devices to seal the opening through which the motor shaft extends, such as with a gasket, to try to prevent the powder from reaching the motor itself. Some powders are abrasive and can damage the motor, and therefore it is desirable to keep the powder away from the motor. However, it is difficult to obtain a proper seal, and therefore it is difficult to keep powder from reaching the motor in a conventional powder feed device.

The powder feed assembly of embodiments of the invention further comprises a carrier gas inlet **68** to enable a carrier gas to be introduced into the motor housing **66** to create a positive pressure within the motor housing to prevent powder from entering the motor housing. A carrier gas supply hose (not illustrated) would be affixed to the carrier gas inlet **68** and to a carrier gas supply tank (not illustrated). The carrier gas exits the motor housing **66** through a carrier gas outlet **94** defined in the bottom of the motor housing **66**. Some of the carrier gas also exits the motor housing **66** and enters the chamber **20** via the shaft openings **64** and openings **65** in the motor housing base **93** (as well as exiting the motor housing **66** through any other gaps in the motor housing base **93**). The path of the carrier gas is illustrated by the arrows in FIG. **1**. Using the carrier gas to pressurize the motor housing **66** helps prevent powder from entering the motor housing **66** and reaching the motor **60**. Such an arrangement eliminates the need to seal the motor shaft opening and is therefore superior to conventional powder feed devices.

The powder feed assembly of embodiments of the invention further comprise a receiving funnel **70** positioned to receive powder exiting the chamber **20** through the gap **22**. A powder outlet **72** is defined in the bottom end of the receiving funnel **70** to direct the powder to a hose (not illustrated) that is connected to the powder outlet **72**. The hose in turn is connected to a thermal spray apparatus (not illustrated). During operation, powder that is pushed out of the chamber **20** by the blade falls into the circumferential slots **75** in the motor housing base **93** and further into a circumferential channel **74** defined between the receiving funnel **70** and the motor housing **66** and then into the receiving funnel **70** and out of the receiving funnel through the hose connected to the thermal spray apparatus. The carrier gas propels the powder all the way to the thermal spray apparatus.

A pressure-equalizing pipe **80** fluidly connects the chamber **20** and the receiving funnel **70** to enable pressure equalization therebetween.

In operation of the powder feed assembly of embodiments of the invention, a powder to be fed to a thermal spray apparatus (or any other suitable apparatus) is placed into the chamber **20** of the powder hopper **12** of the powder feed assembly **10**, via opening **44**. The motor **60** is activated, which rotates blade **14**. The rotating blade pushes powder out of the chamber **20** through the gap **22**, and the powder falls into the receiving funnel **70**. A carrier gas (not illustrated) is introduced into the motor housing **66** via the carrier gas inlet **68**. The carrier gas exits the motor housing **66** into the receiving funnel **70**, as well as into the chamber **20** via the openings **64** and **65**. The carrier gas travels with the powder out of the receiving funnel **70** and into the hose (not illustrated). Some of the carrier gas also travels between the receiving funnel **70** and the chamber **20** via the pressure-equalizing pipe **80**.

The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the invention. As used herein, the singular forms "a", "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises" and/or "comprising," when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

The corresponding structures, materials, acts, and equivalents of all means or step plus function elements in the claims below are intended to include any structure, material, or act for performing the function in combination with other claimed elements as specifically claimed. The description of the present invention has been presented for purposes of illustration and description, but is not intended to be exhaustive or limited to the invention in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art without departing from the scope and spirit of the invention. The embodiment was chosen and described in order to best explain the principles of the invention and the practical application, and to enable others of ordinary skill in the art to understand the invention for various embodiments with various modifications as are suited to the particular use contemplated.

That which is claimed:

1. A powder feed assembly comprising:

a powder hopper having a wall and a floor together forming a chamber, a circumferential horizontal gap being defined between the wall and the floor to enable powder to exit the chamber;

a selectively rotating blade having a body portion positioned within the chamber and one or more blade portions at least partially extending into the gap;

a receiving funnel positioned to receive powder exiting the chamber through the gap and to supply the received powder to a hose; and

a porous bushing having a plurality of holes defined therein, a size of the holes selected to permit a carrier gas to exit the chamber through the porous bushing but to not permit the powder to exit the chamber through the porous bushing, the porous bushing being positioned between the chamber and an inner volume of the receiving funnel.

2. The assembly of claim 1, wherein (a) a height of the gap and/or (b) a width of a portion of the floor which extends circumferentially beyond an interior surface of the wall adjacent the gap is selected based on an angle of repose of the powder.

3. The assembly of claim 1, wherein (a) a height of the gap and/or (b) a width of a portion of the floor which extends circumferentially beyond an interior surface of the wall adjacent the gap is selected such that the powder does not exit the chamber through the gap when the blade is not spinning.

4. The assembly of claim 1, wherein (a) a height of the gap and/or (b) a width of a portion of the floor which extends circumferentially beyond an interior surface of the wall adjacent the gap is selected such that the width of the portion of the floor which extends circumferentially beyond the interior surface of the wall adjacent the gap is greater than a distance that the powder extends into the gap beyond the interior surface of the wall adjacent the gap when the blade is not spinning.

5. The assembly of claim 4, wherein the distance that the powder extends into the gap beyond the interior surface of the wall adjacent the gap corresponds to an angle of repose of the powder.

6. The assembly of claim 1, further comprising:

a motor positioned beneath the floor and having a selectively rotating shaft to which the blade is directly or indirectly affixed, the shaft extending at least partially through a shaft hole defined in the floor; and

a motor housing at least partially surrounding the motor and having a carrier gas inlet to enable a carrier gas to be introduced into the motor housing to pressurize the housing.

7. The assembly of claim 1, further comprising:

a pressure-equalizing pipe fluidly connecting the chamber and the receiving funnel to enable pressure equalization therebetween.

8. The assembly of claim 1, wherein at least a portion of the hopper wall is porous, the porous portion having a plurality of holes defined therein, a size of the holes selected to permit a carrier gas to exit the chamber through the porous portion but to not permit the powder to exit the chamber through the porous portion, the porous portion being positioned between the chamber and an inner volume of the receiving funnel.

9. A method of feeding powder comprising:

placing a desired amount of a powder into a powder hopper of a powder feed assembly, the powder hopper having a wall and a floor together forming a chamber, a circumferential horizontal gap being defined between the wall and the floor to enable at least some of the powder to exit the chamber;

selectively rotating a blade of the powder feed assembly to cause at least some of the powder to exit the chamber through the gap, the blade having a body portion positioned within the chamber and one or more blade portions at least partially extending into the gap;

receiving, into a receiving funnel, powder exiting the chamber through the gap;

supplying the received powder to a hose; and

equalizing the pressure between the receiving funnel and the chamber using a pressure-equalizing pipe fluidly connecting the chamber and the receiving funnel;

wherein the powder feed assembly further comprises a porous bushing having a plurality of holes defined therein, a size of the holes selected to permit a carrier gas to exit the chamber through the porous bushing but to not permit the powder to exit the chamber through the porous bushing, the porous bushing being positioned between the chamber and an inner volume of the receiving funnel.

10. The method of claim 9, wherein (a) a height of the gap and/or (b) a width of a portion of the floor which extends circumferentially beyond an interior surface of the wall adjacent the gap is selected based on an angle of repose of the powder.

11. The method of claim 9, wherein (a) a height of the gap and/or (b) a width of a portion of the floor which extends circumferentially beyond an interior surface of the wall adjacent the gap is selected such that the powder does not exit the chamber through the gap when the blade is not spinning.

12. The method of claim 9, wherein (a) a height of the gap and/or (b) a width of a portion of the floor which extends circumferentially beyond an interior surface of the wall adjacent the gap is selected such that the width of the portion of the floor which extends circumferentially beyond the interior surface of the wall adjacent the gap is greater than a distance that the powder extends into the gap beyond the interior surface of the wall adjacent the gap when the blade is not spinning.

13. The method of claim 12, wherein the distance that the powder extends into the gap beyond the interior surface of the wall adjacent the gap corresponds to an angle of repose of the powder.

14. The method of claim 9, further comprising:

activating a motor positioned beneath the floor such that a selectively rotating shaft of the motor is rotated which in turn rotates the blade which is affixed directly or indirectly to the shaft, the shaft extending at least partially through a shaft hole defined in the floor; and

introducing a carrier gas into a motor housing that at least partially surrounds the motor, thereby pressurizing the motor housing.

15. The method of claim 9, wherein at least a portion of the hopper wall is porous, the porous portion having a plurality of holes defined therein, a size of the holes selected to permit a carrier gas to exit the chamber through the porous portion but to not permit the powder to exit the chamber through the porous portion, the porous portion being positioned between the chamber and an inner volume of the receiving funnel.

* * * * *